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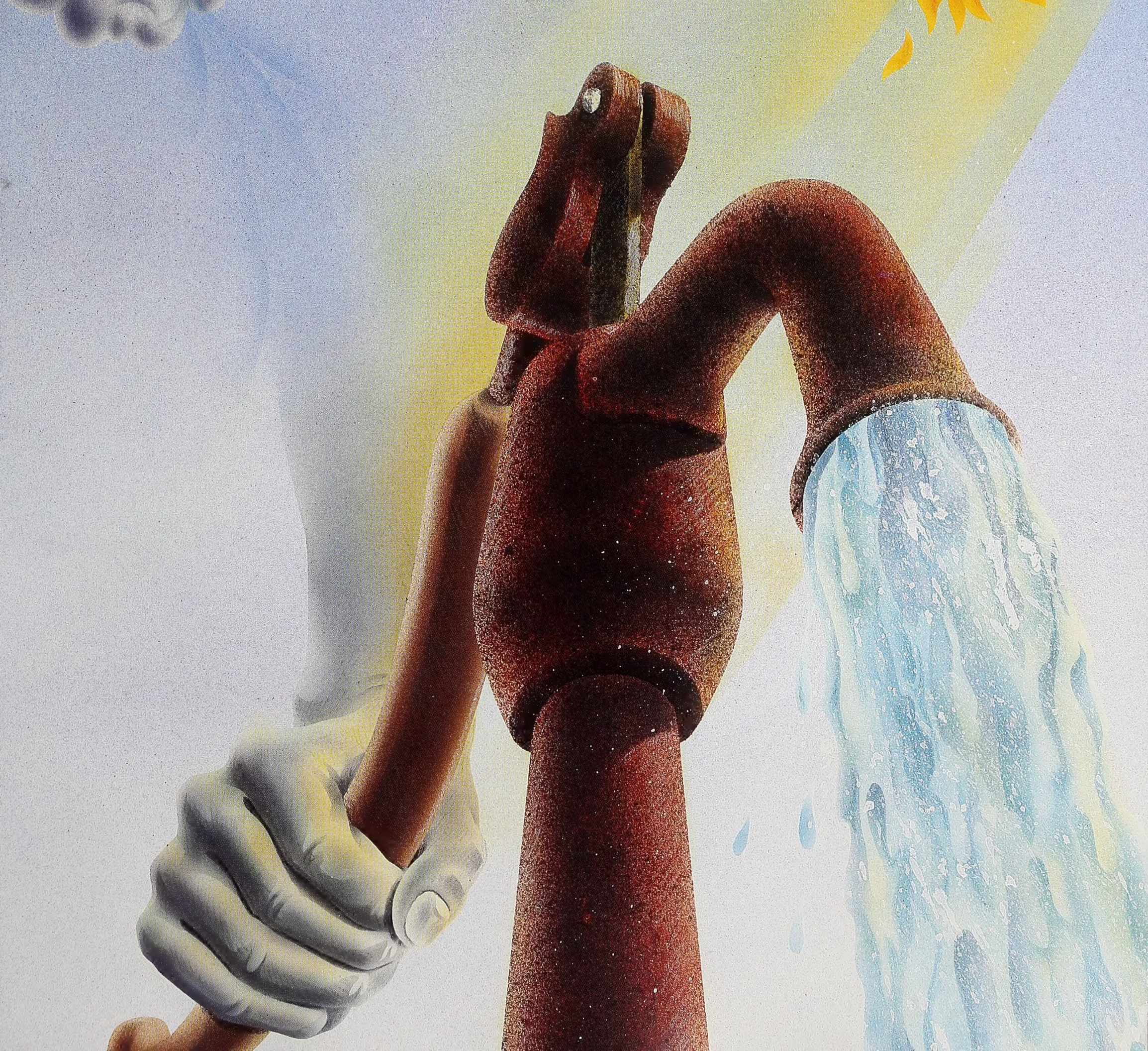
Evaluation of Wind- and Solar-Powered Water-Pumping Systems

A project supported in part by the Alberta/Canada Energy Resources Research Fund



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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Research and Technology Branch of Alberta Energy.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 14.

Evaluation of Wind- and Solar-Powered Water-Pumping Systems

In 1982, a test site was established on the eastern outskirts of Lethbridge for the purpose of evaluating the water-pumping characteristics of wind turbines. Because these devices are in demand by farmers and ranchers who need to draw water in locations that are remote from existing power lines, this test facility was built initially to provide prospective buyers with the data they require to make informed purchasing decisions. It soon became evident, however, that a facility capable of providing independent and unbiased testing was of considerable value to equipment manufacturers, who needed a location where their products could operate over extended periods of time. Thus, several equipment manufacturers were able to develop and improve their products, giving rise to a local wind energy industry. The Lethbridge Wind Research Test Site played a pivotal role in the development of this industry.

With initial funding from the Alberta/Canada Energy Resources Research Fund (A/CERRF) and TransAlta Utilities, as well as Farming for the Future and the Drainage Branch, both of Alberta Agriculture, six water-pumping wind turbines were tested from 1983 to 1985. While this work was under way, the site staff quickly became known as a reliable source of information about Canadian-made or Canadian-distributed wind turbines. Not only did hundreds of people from several countries visit the site each year to observe site operations, but regular open-house events typically attracted 200 or more visitors looking for information and guidance about wind turbines. The activities that were carried out during the 1983/85 period, along with the principal findings, were reported in the technology transfer booklet Measuring and Harnessing Alberta's Wind Resources.

Subsequently, other wind-powered water pumpers and some solar-powered water pumpers were tested from 1985 to 1989, with financial support provided by Energy, Mines and Resources Canada and A/CERRF. The results of this latest body of work are reported here.

General

Throughout the history of the Lethbridge Wind Research Test Site, three research objectives have remained constant. They are as follows:

- evaluate the potential for wind turbines and solar systems to pump water efficiently for agricultural purposes;
- monitor, demonstrate and evaluate various types of wind- and solar-powered water-pumping equipment developed, manufactured or distributed in Alberta and Canada; and
- maintain a Canadian focal point for expertise in the design, evaluation and application of wind- and solar-powered water-pumping systems and related technology.

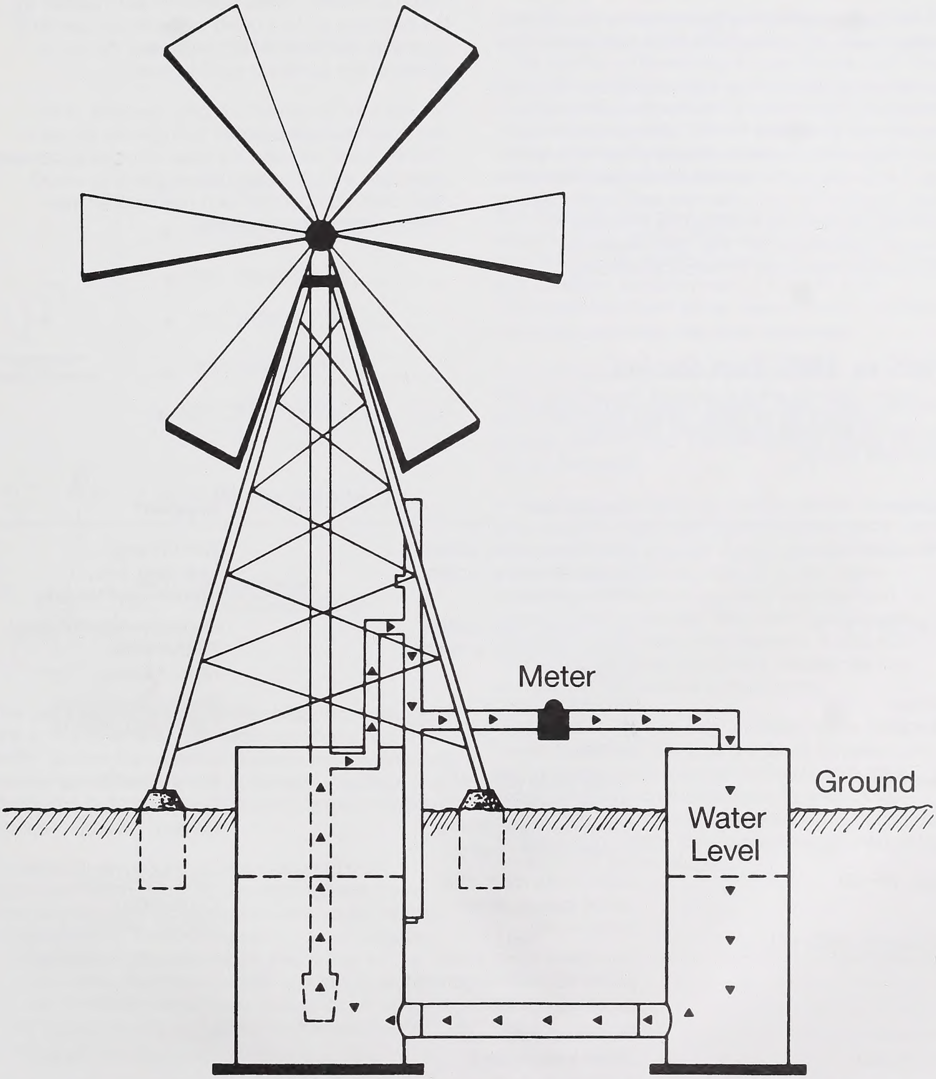
The site is located 1 km east of Lethbridge and is adjacent to a St. Mary River Irrigation District canal. The site is level throughout and is surrounded by flat agricultural fields. This results in minimal interference with wind flow.

To measure the pumping performance of the various machines tested at the site, closed-loop, double-sump systems were installed. In normal operation, the unit being tested pumps water from one sump up a predetermined height, and then into a vented standpipe. The standpipe allows air to be separated from the pumped water and it dampens any pulsating flows before the water is drained through a flow-metered pipe into the second sump. In addition to measurements of water flow, the rotor speed of wind turbines was measured by infra-red sensors.

Atmospheric data needed to relate wind turbine characteristics to pumping performance were provided by the following devices:

- four horizontal wind speed sensors mounted at 7.5 m, 10 m and 12.8 m above ground level on a meteorological tower;
- one wind direction sensor at 10 m;
- one ambient temperature sensor at 10 m and one atmospheric pressure sensor at 2 m;
- local displays of the wind speed and direction; and
- signal conditioners that allowed consistent transmission of sensor outputs to the data acquisition system.

Pumping Circuit



(Source: Lethbridge Wind Research Test Site Evaluation of Wind & Solar Pumping Systems 1985-1987, Paterson, B.A., D.R. Baker and N.E. Jensen, Alberta Agriculture, 1988.)

The solar energy incident on the solar-powered pumping systems was monitored by pyranometers. Also, each solar system was equipped with voltage and current sensors to monitor the power transferred to the pump by the solar panels.

All electronic information generated by the various sensors was sent to a SAFE 8000 data acquisition unit. This device was programmed to sample all sensors and calculate average values and standard deviations. The results of these calculations were transmitted to an IBM PC/XT. The computer was used to produce hourly averages of each sensor's input and daily summary reports of these numbers. Also recorded for each machine was the installation date and downtime periods. This information allowed calculations of "Per Cent Availability", which were measures of machine reliability.

Wind performance curves were calculated for each wind turbine. The procedures followed the Canadian Standards Association (CSA) Preliminary Standard F417-M1986 "Wind Energy Conversion Systems Performance". Also, monthly pumping estimates were calculated. These estimates were based on the pumping system being available for operation whenever the wind speed exceeded the cut-in speed of the particular wind turbine.

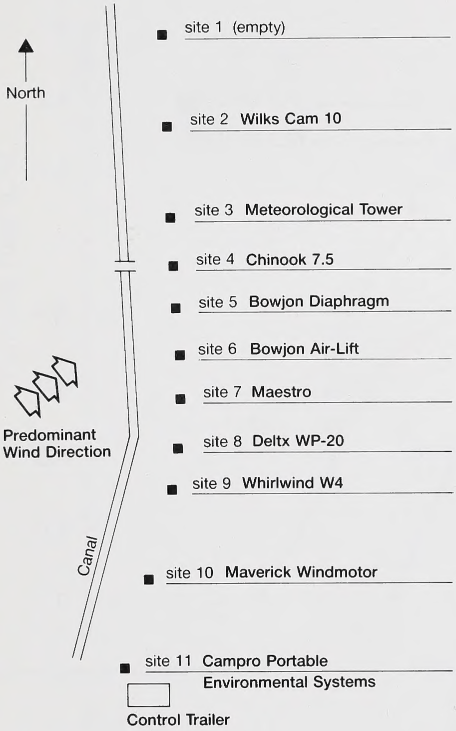
For the solar-powered pumping systems, solar performance curves similar to those for the wind turbines were calculated. Instead of monthly pumping estimates, the potential total volume that would have been pumped by each unit over a three-month period was calculated.

1985 to 1987 Test Period

Over the 1985-1987 period, eight wind turbines and two solar units were tested. They are described below.

Model	Description	Supplier
Wilks Cam 10	Multi-blade rotor, piston pump, driven by a cam/roller system	Wind Energy Unlimited, Inc., Carson City, Nevada
Chinook 7.5	Multi-blade rotor, piston pump, driven by a direct-drive crank	Canadian Agtechnology Partners Ltd., Olds, Alberta
Bowjon (2 units)	Multi-blade rotors, air lift bubbler and diaphragm pumps	Prairie Ditching Ltd., Lethbridge, Alberta
Maestro	Three-blade rotor, AC electric generator with battery storage driving a submersible pump	Nor'wester Energy Systems Ltd., Calgary, Alberta
Deltx WP-20	Eight-blade rotor, dual piston pumps driven hydraulically	Deltx Windpump Corporation, Calgary, Alberta
Whirlwind W4	Two-blade rotor, three-phase AC electric generator, centrifugal pump	Danecraft Mechanical Design Ltd., Calgary, Alberta
Maverick Windmotor	Two-blade rotor, cable-driven helical pump	Massey Enterprises Fort MacLeod, Alberta
Environmental Systems	Arco photovoltaic panels with centrifugal pump	Environmental Systems Canada Ltd., Ingersol, Ontario
Campro Portable	Arco photovoltaic panels with multi-stage centrifugal pump	Cambrian Engineering Group Ltd., Saskatoon, Saskatchewan

Site Layout 1985-1987



The pumping performance was determined for each unit at 5.5 m lift (the Deltx unit was measured at 5 m lift), as was the reliability. Several units experienced mechanical difficulties and underwent modifications during the test period, contributing to low reliability figures.

In earlier investigations, it was observed that machines which pump at low wind speeds have substantially more pumping potential under Alberta conditions than those designed to capture higher wind speeds. This observation was borne out by the data generated in this series of tests. One wind turbine, the Chinook 7.5, was able to cut in at wind speeds as low as 2 m/s, the lowest of any machine tested at the site.

None of the wind turbines produced outstanding performance, however. Each had its own good points, but each also experienced difficulties. The Wilks Cam, for example, showed considerable promise because of its low cut-in speed (2.5 m/s), but pump problems prevented its true potential from being determined.

The Chinook's even lower cut-in speed might have given it some advantage, but it had a low furling speed (11 m/s), which made proper evaluation of the machine difficult according to the CSA test method.

Both Bowjons were modified during the test period, resulting in lowered pumping performance.

The Deltx unit showed very promising pumping performance, but continual mechanical problems reduced its reliability to the lowest of all machines tested. The company has since discontinued manufacturing wind turbines.

The Maestro was designed to produce and store electric energy during high-wind periods. The electricity could then be used to operate the pump at a constant pumping rate of 1.6 L/s, even during low-wind conditions. Battery control problems, however, prevented this from happening.

The Whirlwind W4 began pumping at a relatively high wind speed (4 m/s), but the control system shut down the turbine when winds became greater than 11 m/s. The Windmotor demonstrated similar behaviour.

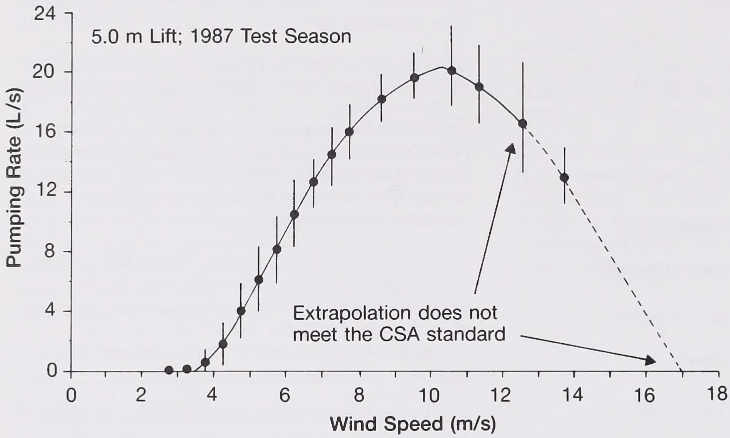
It was concluded that most wind pumps exhibited unacceptably high maintenance requirements. Ideally, a wind-pumping system should operate for 20 years with only annual lubrication and minor maintenance. It was suggested that the wind pumps tested over the 1985-1987 period were unable to meet these requirements. It was also observed that most equipment failures involved pumps, not the turbine components.

In comparing the two solar-powered water pumpers, it was found that the Environmental Systems unit cut in at low levels of solar radiation, making it more suitable than the Campro for areas that experience frequent overcast conditions. In contrast to the wind pumps, solar systems appeared to be consistently more reliable.

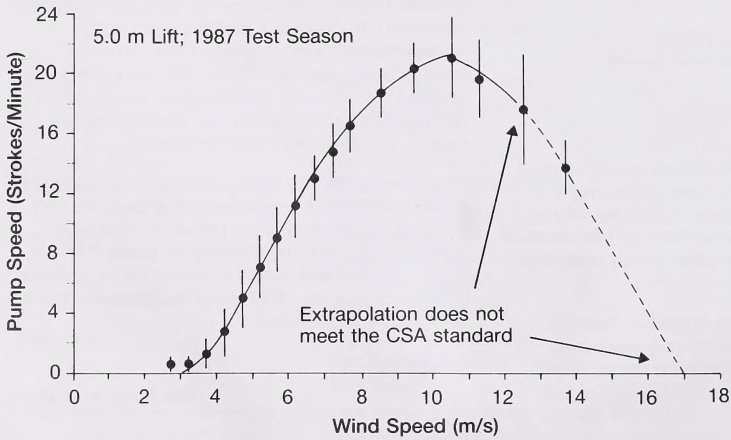
Reliability

Unit	Per Cent Availability
Wilks Cam 10	92
Chinook 7.5	55
Bowjon Diaphragm	71
Bowjon Air Lift	94
Deltx WP-20	24
Maestro	100
Whirlwind W4	100
Windmotor	88
Environmental Systems (Solar)	86
Campro Portable (Solar)	100

Deltx WP-20 Pumping Performance

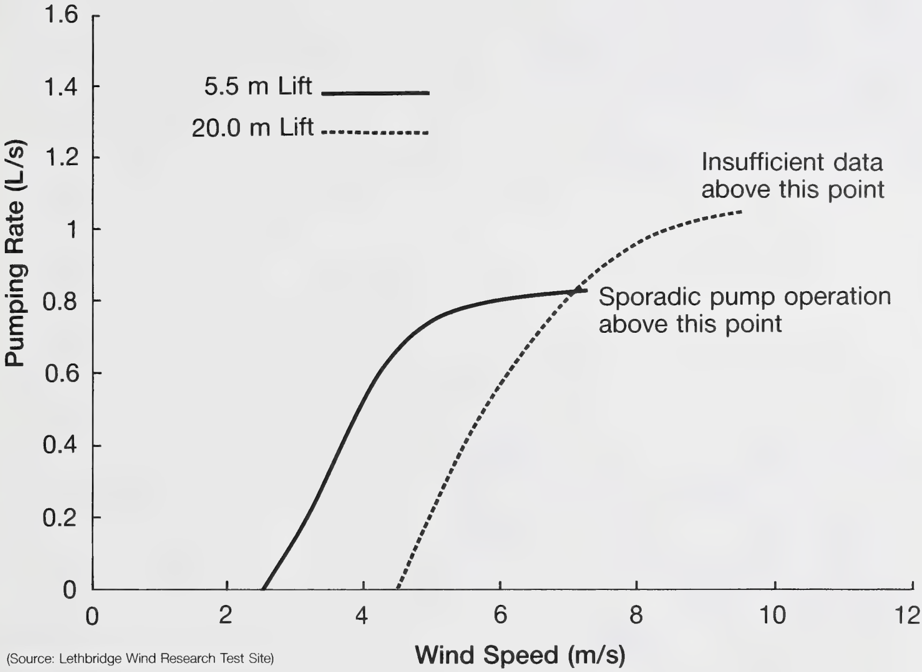


Deltx WP-20 Pump Speed



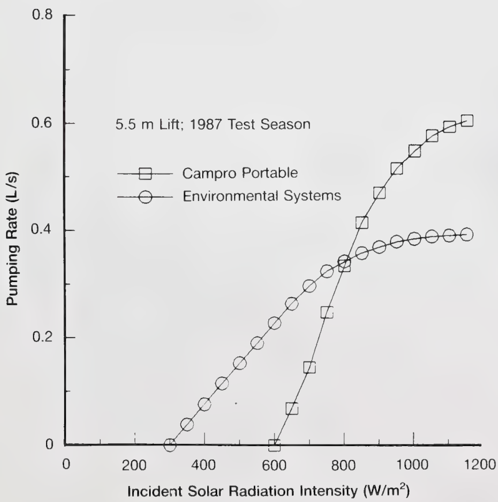
(Source: Lethbridge Wind Research Test Site Evaluation of Wind & Solar Pumping Systems 1985-1987, Paterson, B.A., D.R. Baker and N.E. Jensen, Alberta Agriculture, 1988.)

Wilks Cam Performance Comparison



(Source: Lethbridge Wind Research Test Site)

Performance of Solar Pumpers



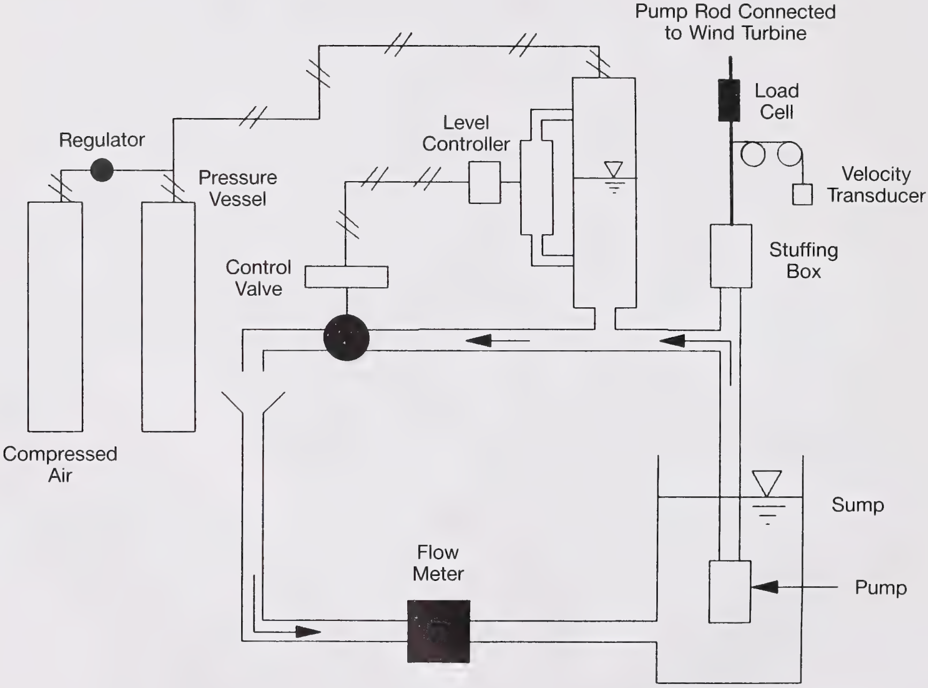
(Source: Lethbridge Wind Research Test Site Evaluation of Wind & Solar Pumping Systems 1985-1987, Paterson, B.A., D.R. Baker and N.E. Jensen, Alberta Agriculture, 1988.)

Deep Well Simulator

The original purpose of the test site was to develop water-pumping systems suitable for the shallow pumping involved in subsurface drainage and cattle watering in the Prairie provinces. It became apparent during the 1985-1987 period, however, that an overseas market existed for reliable wind turbines capable of pumping water from depths greater than normally experienced in western Canada. Thus, a deep well simulator was designed and built to allow testing at depths ranging from 15 m to 250 m.

The design principle of this device involves controlling the working pressure by maintaining a constant pressure within a vessel. The pressure, in turn, acts on the water within a standpipe upstream of the control valve. Thus, a pump being tested must overcome this pressure to deliver water to the standpipe.

Design of Well Simulator



(Source: Lethbridge Wind Research Test Site Evaluation of Wind & Solar Pumping Systems 1985-1987, Paterson, B.A., D.R. Baker and N.E. Jensen, Alberta Agriculture, 1988.)

1988-1989 Test Period

Performance and reliability testing continued during 1988 and 1989. The test periods were extended for the Wilks Cam 10, the Chinook 7.5, the two Bowjon units, the Whirlwind 4 and the Maestro wind turbines. In addition, two models of the Windmotor, as well as Lange and Dutch wind turbines, were tested. Testing continued on the Environmental Systems solar-powered water pumper, as well as on five solar pumpers manufactured by Canadian Agtechnology Partners of Olds, Alberta. All were tested at the customary 5.5 m depth, and some were tested using the deep well simulator.

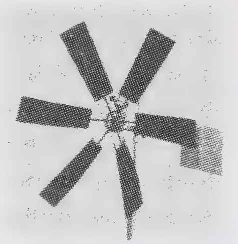
Wind turbines and solar systems tested for the first time during 1988-1989 were as follows:

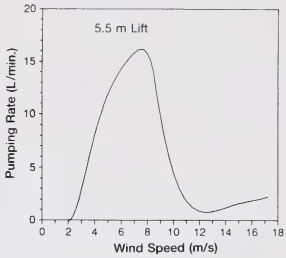
Model	Description	Supplier
Maverick Windmotor I & II	Three-blade rotor, cable-driven, progressive cavity pump	Maverick Wind Energy, Pincher Creek, Alberta
Prairie PD8-6	Multi-blade rotor, air-lift pump with direct-drive air compressor	Prairie Ditching, Lethbridge, Alberta
Lange	Multi-blade, vertical axis rotor driving a DC generator (no pump)	Lange Wind Turbines, Linden, Alberta
Dutch	Multi-blade rotor, piston pump, driven with a direct-drive crank	Dutch Industries, Regina, Saskatchewan
CAP Solar Pump 675TJ	Six Arco photovoltaic panels driving a proprietary pump	Canadian Agtechnology Partners, Olds, Alberta
CAP 1 Panel/Battery	One Solarex photovoltaic panel charging an 18 volt battery to run a diaphragm pump	Canadian Agtechnology Partners, Olds, Alberta
CAP 2 Panel	Two tracking Arco photovoltaic panels driving a diaphragm pump	Canadian Agtechnology Partners, Olds, Alberta
CAP 4 Panel	Four tracking Arco photovoltaic panels driving a centrifugal pump	Canadian Agtechnology Partners, Olds, Alberta
CAP 8 Panel	Eight Arco photovoltaic panels driving a progressive cavity pump	Canadian Agtechnology Partners, Olds, Alberta

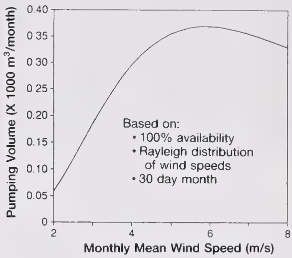
Lethbridge Wind Research Test Site

1989 Performance Test Results

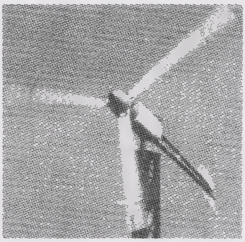
Prairie #PD8-6

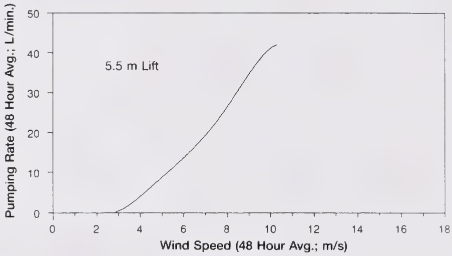




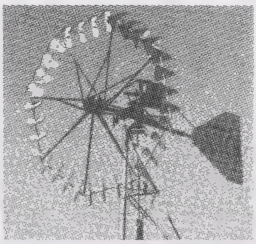


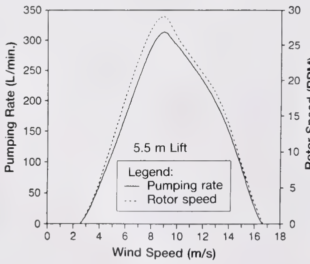
Maestro

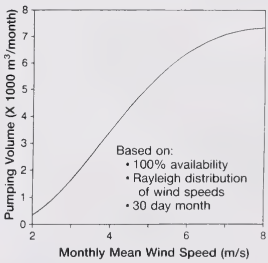




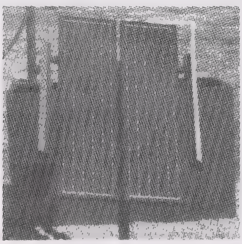
Dutch

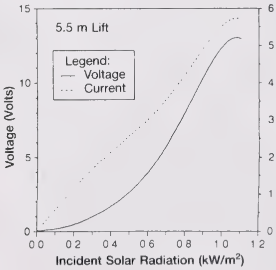


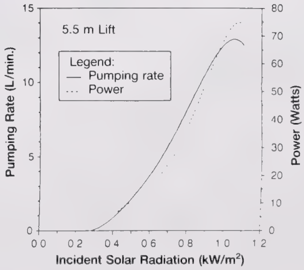




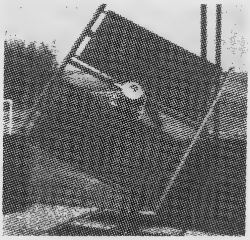
CAP 2 Panel

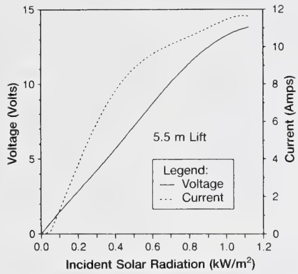


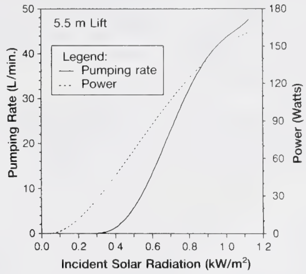




CAP 4 Panel







(Source: Lethbridge Wind Research Test Site Evaluation of Wind & Solar Pumping Systems 1988 - 1989, Final Report, Paterson, B.A. and D.R. Baker, Alberta Agriculture, 1990.)

Site Layout 1988 - 1989

Results

The earlier characteristics of the Maverick Windmotor were confirmed. It cuts in at 3.5 m/s and reaches its maximum performance at 13 m/s. Its reliability improved to 100 per cent.

The pump valve problems experienced by the Wilks Cam continued, making it difficult to obtain reliable performance data for more than one week during the 387-day period the unit was on the test site. Some testing with the Deep Well Simulator was also carried out.

During the 1988 test season, the reliability of the Chinook 7.5 improved from the previous value of 55 per cent to 70 per cent. This unit was also tested with the Deep Well Simulator. Problems continued with some mechanical components, and the manufacturer eventually decided not to proceed with making improvements.

The Prairie PD8-6 showed encouraging results, especially for a design that is at an early stage of development.

It was found that the Lange was incapable of producing enough power to drive any pumps. Thus, development of this design was terminated.

The Maestro continued to show promise, but the battery system also continued to experience problems. The manufacturer has indicated a willingness to make changes to enhance the performance of this wind turbine. Over two test seasons, the reliability of the unit was 94.6 per cent.

During 1988, a different pump was used with the Whirlwind, but its performance was worse than with the previous pump. Deep well testing was carried out as well. Subsequently, the manufacturer went out of business.

The Dutch is a low-speed version of the delta-blade concept used in the Deltx WP-20. Its pumping performance was rated as promising, and it had a reliability rating of 96.1 per cent during its first test season.

The Environmental Systems solar-powered water pumper continued to demonstrate reliable performance, and was inoperative only once in five years. This was because the pump lost its prime.

Of the five solar units made by Canadian Agtechnology Partners, three showed reliability ratings of 100 per cent, and were tested extensively with the Deep Well Simulator. This testing has allowed the company to design and manufacture its own pumps.

Other Services

A solar-powered water pumper manufactured by Canadian Agtechnology Partners, and installed near Bow Island to lift the outflow from a deep interceptor ditch to an adjacent canal, was monitored during 1989 on behalf of the St. Mary River Irrigation District. The system consisted of two, six-panel tracking units powering a single-stage, axial-flow pump. The maximum lift was 3.4 m. During the monitoring period, the system pumped an average of 27.1 m^3 a day, and had a reliability rating of 95.8 per cent. This was considered to be a very satisfactory performance.

A data base and computer software were created to help manufacturers design stand-alone wind systems. The data base is the result of analysing 16 years' worth of hourly wind speed data from 25 locations in the southern portion of the three Prairie provinces. This information, published in tabular form, provides sufficient data to determine the required size of a wind turbine and its associated storage system for a variety of applications.

The software package, used in conjunction with the data tables, can be used to determine the number of turbines required to pump a specified volume of water, and can help in choosing the associated storage system.

In addition to testing some wind turbines, the Deep Well Simulator was used to test seven pumping systems. The simulator was used for two-thirds of the 1988 test season and during the entire 1989 season.

Marketing

It was estimated that the potential market for water-pumping systems in Canada numbers in the thousands. Most of this market involves livestock watering and irrigation/subsurface drainage. In the Prairies alone, an estimate of 30 000 installations was considered realistic. Currently, more than 100 wind-powered water-pumping systems are operating in Alberta, and over 800 have been installed in Saskatchewan and Manitoba.

It was noted, however, that if the wind industry hopes to make further inroads, more reliable machines must be produced. Although solar systems are more expensive, sales have risen dramatically over the past two years, primarily because of system reliability.

It was urged that development of Canadian-made water pumpers should be encouraged because the state-of-the-art is not well-advanced anywhere in the world. Therefore, Canadian manufacturers stand a good chance of producing units that would be accepted widely in both Canadian and overseas markets.

The export market for water-pumping systems is many times larger than the domestic market, and would include water pumping for domestic purposes in addition to livestock watering and irrigation. Penetration of this market not only depends on the equipment being reliable, but also ensuring the components of the system can be repaired locally.

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Contact

For more information about the operation of the wind research test site, and detailed data regarding specific wind and solar systems, contact:

B.A. Paterson
Project Manager
Lethbridge Wind Research Test Site
Alberta Agriculture
Lethbridge, Alberta
T1J 4C7

Telephone: (403) 381-5515

Additional copies of this publication are available from:

Information Centre
Alberta Energy/Forestry,
Lands and Wildlife
Main Floor, Bramalea Bldg.
9920 - 108 Street
Edmonton, Alberta
T5K 2M4

Telephone: (403) 427-3590

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Alberta Energy/Forestry,
Lands and Wildlife
Main Floor, Britannia Bldg.
703 - 6th Avenue S.W.
Calgary, Alberta
T2P 0T9

Telephone: (403) 297-6324

For more information about A/CERRF, contact:

Senior Manager,
Technology Development
Research and Technology Branch
Alberta Energy
3rd Floor, Blue Cross Place
10009 - 108 Street
Edmonton, Alberta
T5J 3C5

Telephone: (403) 427-8042

Telex: 037-3676

Fax: (403) 422-0975

For more information about Alberta Energy's renewable energy research programs, contact:

Senior Research Manager,
Research and Technology Branch
Alberta Energy
3rd Floor, Blue Cross Place
10009 - 108 Street
Edmonton, Alberta
T5J 3C5

Telephone: (403) 427-3713

Telex: 037-3676

Fax: (403) 422-0975

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Southwest Alberta Renewable
Energy Initiative
Information Centre
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P.O. Box 2068
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T0K 1W0

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Other publications in this series that deal with renewable energy include:

Solar Energy Potential for Alberta, 9 pages, March 1986. (Reprinted 1990).

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